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Wind-Solar-Hydel Cogeneration Systems in Remote Areas

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Abstract*:* This paper proposes a control strategy for accomplishing reliable coordination of wind-solar-hydel energy conversion systems in islanded mode of operation. With this integrated scheme, it is viable to generate electrical power from inexhaustible resources in regions having favourable meteorological conditions with limited or no connectivity to grid. In this work, the control technique is formulated to utilize the available renewable energy sources in an efficacious manner to render power at almost constant voltage and frequency to the isolated load. The control strategy of this wind – solar – hydel cogeneration system is implemented by using simulation software and its effectiveness and working is demonstrated through simulation results.

I. INTRODUCTION

Renewable Energy Resources is considered as the future source of power generation, because of cost free availability of natural resources. Normally the hybrid systems are reliable and economical. In general load demand of hilly and rural areas is low and to meet the load, wind and solar power are widely used energy resources. In conjunction to these resources, other resources like Biomass, Tidal, Hydro and Geothermal etc. can also be used to meet the fluctuations in load demand. For the effective utilization, all the renewable energy conversion systems can be coordinated together to form a hybrid energy conversion system. The power extracted from renewable sources can either be connected to the grid or consumed locally [2]. Those modes are respectively known as grid connected and islanded modes. In remote areas and small islands, the population is very sparse and the power requirements are very low. Hence, extending the grid lines to such localities is unduly expensive. Since the inexhaustible resources are naturally distributed, energy can be extracted from those resources without the need for extensive transmission systems.

II. LITERATURE SURVEY

Autonomous operation of isolated systems of locally distributed energy resources has attracted major utilities all over the world. With this trend, the supply distribution could certainly be improved and also the duration of the power outage could be reduced [4]. The islanding process can be caused by disturbances, such as fault or as a result of intentional islanding events due to maintenance requirements. After disconnection from the main grid, the isolated hybrid system experiences frequency and voltage deviations. The isolated system is expected to remain operational after islanding and meet the corresponding load requirements during autonomous operation. The wind turbine based hybrid system is found to be promising candidate for remote power generation due to availability of dispersed wind resources, environmental friendly power generation and rapid technological development. A simulation study was performed to show that the dynamic performance of the system could be improved by minimizing the frequency deviations and improving bus voltage regulation. When wind

generators are tied with the utility grid, the system voltage and frequency are virtually constant and independent of wind flow variations. However, in case of small autonomous networks integrating wind-diesel generator units, wind power fluctuations significantly affect the system voltage and frequency. The fluctuation in system voltage is primarily due to deficit in reactive power exchange between load and source. Hence control of reactive power is a vital phenomenon for alleviating voltage fluctuations in hybrid power systems. In a novel scheme was proposed to mitigate voltage fluctuations through reactive power compensation. Later, a technique was proposed for reactive power compensation using artificial neural network tuned static VAR compensator for stand-alone wind-diesel-micro hydro system. The modern trend in power electronics technology involves integration of renewable energy sources and energy storage systems. This technique would really enhance voltage stabilization by sustaining the voltage level of generator despite variation in wind speeds and solar irradiance. From the literature, it is understood that there exist challenges in establishing reliable coordination among different energy conversion systems (ECS). For the controller to be effective, it is expected to

- establish stable coordination of wind, solar and hydro energy conversion systems,
- minimize the voltage and frequency fluctuations, and
- extract maximum energy from the natural resources

Considering the existing literature on deriving the energy from renewable sources, this work is aimed at establishing the coordination among the wind, solar and hydro energy conversion systems of isolated region. For the reliable coordination, the proposed controller is to be equipped with energy storage schemes like batteries or ultra capacitors, and should make use of Maximum Power Point Tracking (MPPT) algorithms.

III. Existing System

The weather data under study is presented in the appendix of this paper. The block diagram of the isolated power system is shown in Fig. 1 below.

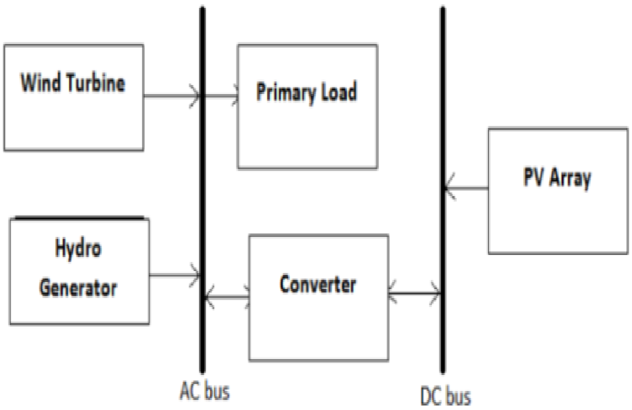

Fig. 1 Block diagram of isolated power system

IV. Proposed Method

The configuration of the proposed hybrid power system is depicted in Fig. 2. It consists of Wind Energy Conversion System (WECS), Solar Energy Conversion System (SECS), Hydro Energy Conversion System (HECS), and Battery – Energy Storage Scheme (B-ESS), common DC bus and power electronic converters.

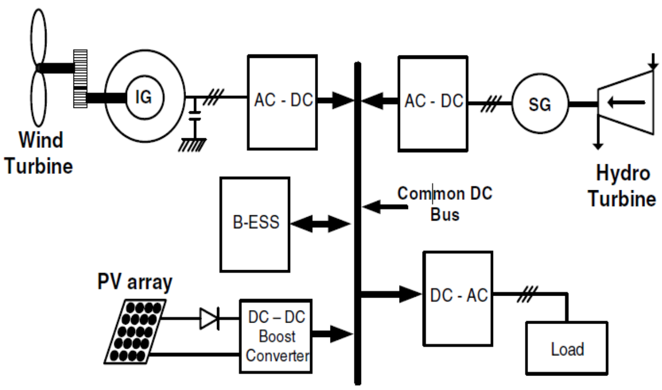

Fig. 2 Configuration of hybrid energy conversion system

The wind energy conversion system is composed of wind turbine, gear mechanism, induction generator, AC-to-DC converter for conditioning the power available from the generator. The PV system consists of a PV array, power diode to prevent reverse current flowing into the PV array and a DC-to-DC converter for boosting the array voltage. Hydro

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energy conversion system consists of hydro turbine coupled to synchronous generator, a power converter to rectify the AC voltage from synchronous generator. Each ECS delivers DC voltage after rectification and filtering through capacitor. This technique enables easier coordination of all ECS through a common DC bus. It can also mitigate the voltage fluctuations of the common DC bus. The B-ESS also aids in stabilising the generator output power if there is high frequency turbulence in wind speeds.

V. CONTROL STRATEGIES

The Wind, Solar and Hydro Energy Conversion systems can be coordinated in one of the following modes of operation (a) grid-tied mode, (b) islanded mode. In grid tied mode, the hybrid energy conversion system transfers power to the grid, based on the prevailing atmospheric conditions. In this work, control strategies referring to islanded-configuration is deployed for servicing load requirements. A control technique is devised for each ECS to extract maximum power available from natural resources. One of the defiance associated with wind energy based generation is that, the input torque which is dependent on wind speed is incessantly varying and hence the power available from generator and its terminal voltage are variable as well. In similar fashion the dc power available from solar photovoltaic panel deviates from nominal value due to unpredictable atmospheric conditions. In order to extenuate the variation in major system parameters, such as frequency, voltage and power levels, a control technique is devised. The controller monitors the environmental and system parameters of each ECS and transfers control signals. The PWM based voltage-sourced converters associated with WECS and SECS maintain voltage, frequency levels inspite of minor deviations in wind speed, solar irradiance and load fluctuation through power regulation schemes. The governor mechanism deployed for hydro turbine coupled to synchronous generator would regulate the ac power voltage level within permissible limits. The ac power available from induction and synchronous generator would be converted to dc power of desired voltage level. The dc power available from SECS is paralleled with DC bus through boost converter. This would ensure the coordination of power available from all the ECS despite chaotic weather conditions. The DC power available in the common DC bus is converted to ac power having adequate voltage and frequency by PWM power electronic converter that suffices the load requirements.

A. Wind turbine - Induction Generator controller

The model of wind turbine is based on the steady-state characteristics of the turbine. The wind turbine control system should extract the maximum power available from varying wind velocities. At lower wind speeds the wind turbine angular velocity is regulated to capture maximum energy to the possible extent. The following equation dictates the mechanical power available at the shaft of wind turbine.

Incessant variation of wind speeds would result in variation of input torque to wind turbine. In order to compensate for varying wind speeds, pitch control scheme (Fig. 4) is deployed to regulate the blade angle of wind turbine to maintain optimum tip-speed ratio. The pitch control scheme also maintains the generator terminal voltage and power levels close to nominal values. This would enable the turbine to operate at maximum power coefficient to extract maximum power. In the induction generator based wind power unit, the real and reactive power to the load is controlled by the schemes illustrated in Fig. 5

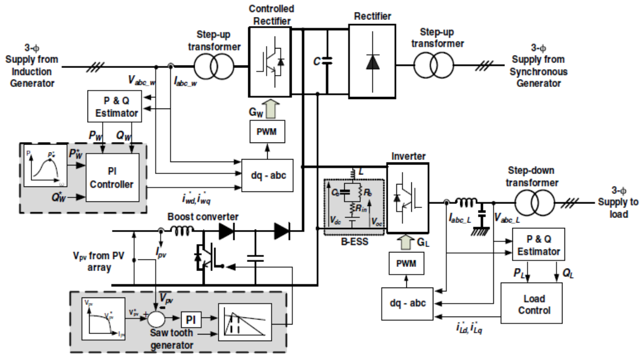

Fig. 3 Schematic of control strategy for hybrid energy conversion system

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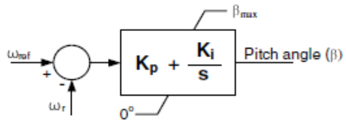

Fig. 4. Pitch angle controller

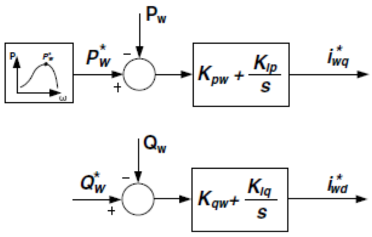

Fig. 5 Power controller for WECS

B. PV array - MPPT controller

The cells must be connected in series-parallel configuration (PV array) for achieving desired terminal voltage and current. For efficient operation, the PV array has to operate at maximum power point. Here the incremental conductance method is implemented for maximum power extraction from the PV array under operating conditions. The MPPT technique deploys PI controller for capturing maximum power under prevailing atmospheric conditions. This control schematic is depicted in Fig. 6

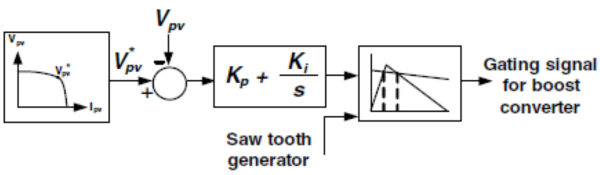

Fig. 6 MPPT control for SECS

C. Hydro Turbine - Synchronous Generator

The block diagram in Fig. 7 represents the dynamics of a hydro turbine, with a penstock (assuming a non-compressible fluid with a rigid conduit) without the inclusion of surge tank. The model is designed adhering to the laws of angular momentum.

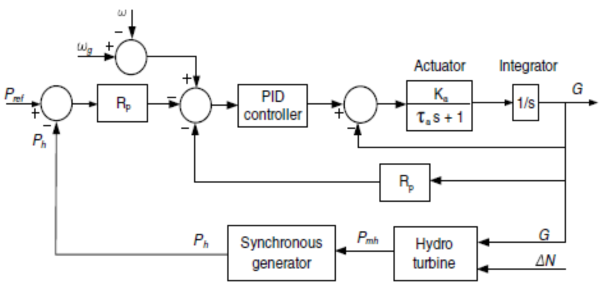

Fig. 7 Hydro turbine governor mechanism

VI. Results and Discussion

To assess the dynamic performance of hybrid control scheme, simulation was performed considering load variation of 1.4 - 1.53 MW. The conventional control technique implemented here is designed to maintain voltage, frequency stability and also power sharing among ECS when there are variations in load profile and weather conditions.

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A. *Performance of WECS*

The performance of WECS controller is shown in Fig. 8. It can be seen that for wind velocity of 10 m/s, WECS system (300 kW) can deliver 180 kW (0 - 1.5s) and 210 kW (1.5 - 5s) for considered load variation (Fig. 8(c)) . The dynamic stability of the WECS can be understood from Fig. 8(b)-(d). The pitch angle regulator maintains blade angle of wind turbine around 9.8°, thus maintaining induction generator speed almost constant, despite fluctuations in load and minor deviations in wind speed.

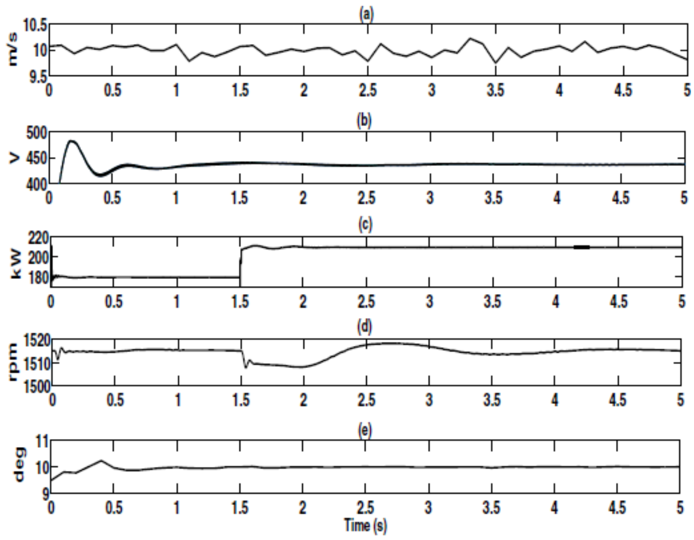

Fig. 8 Performance of WECS

(a) wind speed, (b) generator voltage, (c) real power delivered, (d)generator speed, (e) pitch angle

B. *Performance of SECS*

The solar energy conversion system is designed to deliver 320 kW of real power. The performance of SECS is illustrated in Fig. 9. For 1 kW/sq.m solar insolation, the array voltage is maintained at 820 V for a load current of 390 A (Fig. 9 (c),(d)). With incremental conductance MPPT technique the real power delivered is 320 kW (Fig. 9(e)).

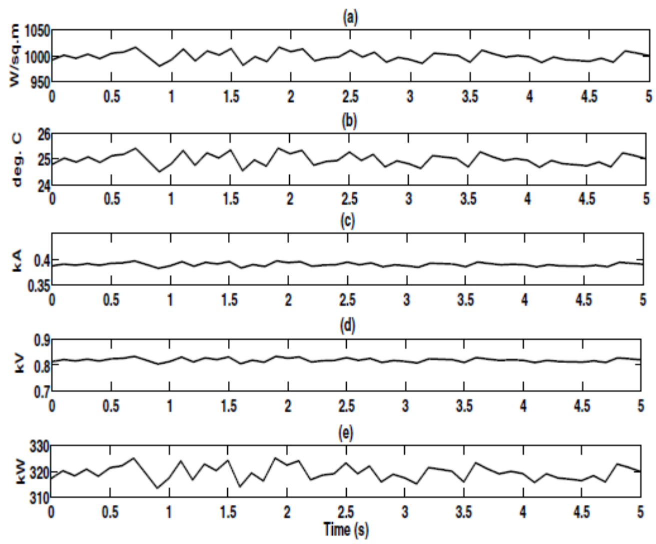

Fig. 9 Performance of SECS

(a) solar insolation, (b) cell temperature, (c) PV array current, (d) PV array voltage, (e) real power

C. *Performance of HECS*

The HECS unit (1 MW) renders 900 kW (0 - 1.5s) and 1000 kW (1.5 - 5s) when load varies from 1.4 - 1.53 MW (Fig. 10(c)). From Fig. 10(d), it is clear that generator speed is restituted to 1500 rpm by the governor mechanism.

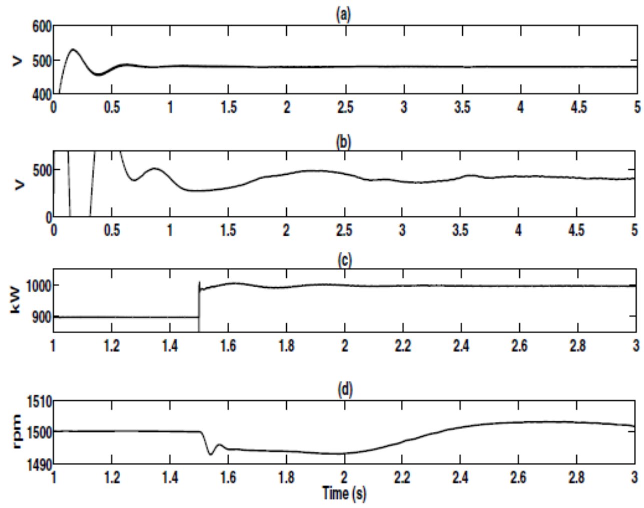

Fig. 10 Performance of HECS
(a) generator voltage, (b) excitation voltage, (c) real power delivered, (d) generator speed

D. *Performance of B-ESS*

With the B-ESS, the power available from natural resources is stored in the battery pack during the interval 0 - 2.5 s. In case of local grid faults, the B-ESS is capable of delivering the stored energy to the loads for a short duration. This can be seen from Fig. 11(a). The battery state-of-charge is also shown in Fig. 11(b).

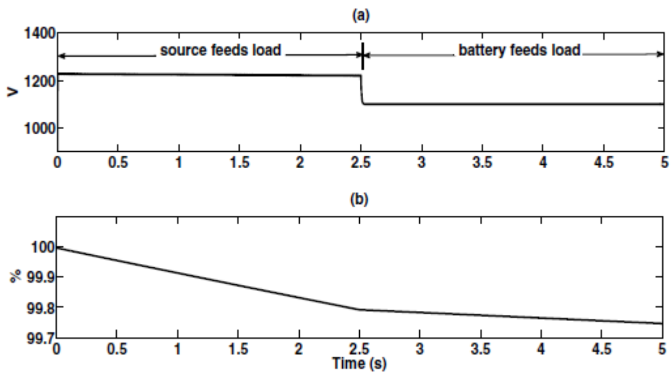

Fig. 11 Performance of B-ESS (a) load voltage, (b) state-of-charge

E. *Performance of Integrated Scheme*

The terminal voltage of induction and synchronous generators are stepped up and rectified to obtain DC voltage of 1225 V (Fig. 12(a)). The output of PV array is paralleled with DC bus voltage through boost converter. The dynamic stability of hybrid control scheme is indicated in Fig. 12(c)-(e) for a load variation of 1.4 MW - 1.53 MW. The voltage and frequency stability of hybrid scheme despite load fluctuation ensures efficaciousness of control strategy.

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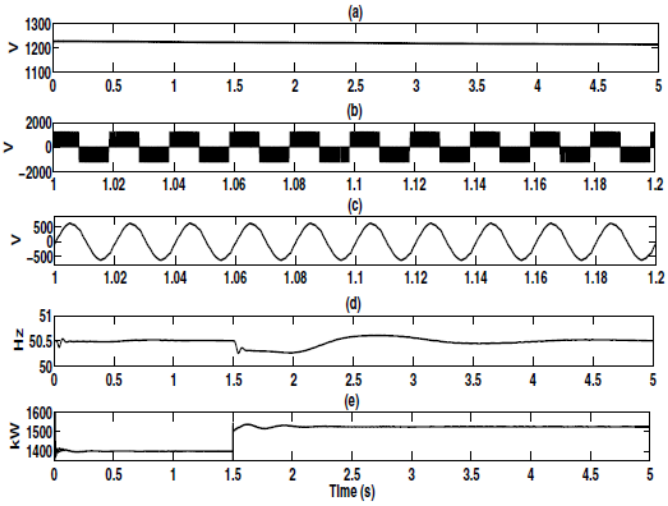

Fig. 12 Performance of integrated scheme
(a) DC bus voltage, (b) inverter output voltage (line-line),
(c) load voltage (line-line), (d) frequency,(e) total real power delivered by hybrid scheme

VII. Conclusion and Future Work

In this work, a control technique was contrived for establishing reliable coordination among wind, solar and hydro energy conversion systems in islanded mode. The proposed control strategy was implemented in MATLAB platform. The performance of individual ECSs and the overall hybrid system are demonstrated through simulation results. As the results are promising, the proposed control strategy would be implemented in real-time on scaled down model.

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Biographies

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